



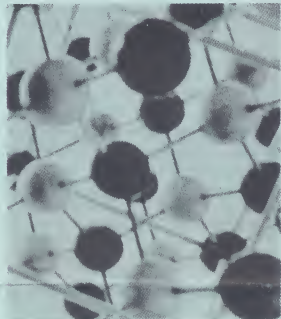
edited by Sam Kass

THE TIP-OFF

ON COMPONENTS FROM SCHWEBER/FEBRUARY, '66

THE SEMICONDUCTOR STORY

Overture on a Familiar Theme



Model of Atomic Crystal Lattice

Solid State physics has many branches; the one best known to the public pertains to a class of solids called semiconductors. It is so well known that the phrase *Solid State Age* is often used as a rhetorical symbol for semiconductors alone, blithely ignoring such important solid state areas as superconductivity, lasers, luminescence, structural analysis, etc. Ages can be born unbaptized, and the *Solid State Age*, though born in 1900 when Max Planck postulated the Quantum Theory, was not firmly and formally tagged until the transistor burst upon the scene in 1947, trailing behind it the enormous potential which even now has not been exhausted.

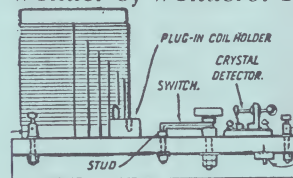
The phrase "*Solid State Age*" may seem pompous; indeed the many trail-blazing inventions and breakthroughs of the 20th Century, all endowed with that patent of nobility we call an Age, may seem like a mountain of pomposities, fabled images dreamed up by public relations puppeteers. One need only look at the list of ages coined in our century — it is a long one: (to begin with the A's) the Atomic Age, the Automated Age, the Aspirin Age . . . But why not? On second thought, why should we not have a proliferation of Ages in this century? It is a matter of record that there are more scientists living and working today than in all the preceding centuries together. Nor should one be surprised that scientific research literature is growing at an exponential rate, doubling about every dozen years. Is it any wonder then that in this century an Age is born every decade and a "generation" lasts half that time?

It would be wrong of course to assume that an Age will pop up every decade on the hour like a crocus in early Spring. There is no fixed gestation period although a gestation process is involved. One can't predict a forthcoming Age by correlating the current rate of growth with past growth rates. Correlation only reveals the simple fact that the speed of change keeps grow-

ing faster, something we already knew. The fact is that Age-producing breakthroughs occur haphazardly. Yet the haphazard event is preceded by a steady accumulation of bits of knowledge that ultimately generate the final breakthrough. Taking a backward glance at the semiconductor story as the bits of research accumulate like budding sprouts waiting for the day of harvest is to be the main project of our next few issues — we hope.

It is not being written with the engineer in mind, though he is welcome to read if he promises not to carp. Nor is it intended for that mythical individual "the non-technical reader," since we don't think he exists. Anyone who can count digitally is technical enough for us—which takes care of the mathematics. As for the rest, all you need is the power of the imagination, whether it is fantastic, visionary, creative, or poetic, it will turn the trick for you. If there is a purpose to this project, it may well be the chance it offers to evoke the remembered pleasures and thrills of a bygone era that was fondly loved.

Wonder of Wonders: The Crystal Radio Set



Crystal Radio — Vintage 1920

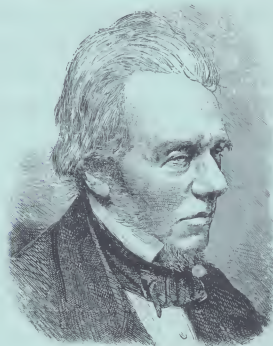
The fact is that the earliest radios for home use were solid state by virtue of the semiconducting crystals which they used for detection. Immediately after World War I these crystal sets became an ornament of every living room and huge 100 to 200 foot antennas, called aerials in those days, sprang up on myriad rooftops like some strange species of spider webs, hopefully strung up to achieve the maximum pickup of energy radiated by the transmitting antenna. The crystal set was designed simply to receive the audio signal wrapped up in its radio carrier, abstract the signal and discard the carrier like a torn-open envelope. Though some slight gain was afforded by other components of the crystal set, the crystal itself was entirely guiltless of any amplification.

The crystal detector was so inexpensive it seemed a shame it could not be made to amplify. This thought sparked a trail of research that

The phrase Solid State is not usually associated with radio equipment before the coming of the transistor, but

finally culminated in the discovery of an amplifying diode, just as the crystal itself was the end-result of an equally long search that dated back to the middle of the 19th century. This research continued unrelentingly, if slowly, through the era of the vacuum tube, picking up added strength as the usable radio frequency range soared into the microwave region where vacuum tubes are troublesome. The transistor solved the problem of a solid state amplifying device, but its two-junction mechanism seemed to imply that a single-junction device could never be made to amplify. But eventually the persistence of man was rewarded when Dr. Leo Esaki described his "tunnel" diode in a one-page letter to the editor of the *Physical Review* of January 1958. Another breakthrough occurred in 1963 when J. B. Gunn discovered that a small crystal of gallium arsenide could be made to oscillate at 1,000 megahertz (MHz) when surrounded by a high electric field. But let us go back. . . .

The Electrical Age Takes Shape

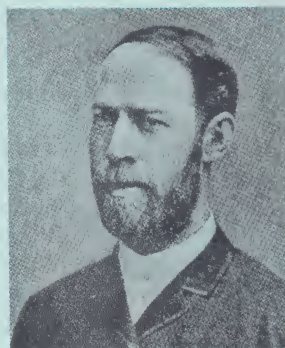


MICHAEL FARADAY

... all the way back . . . to Faraday's fundamental experiments with magnets in 1831, and a triple play in which three men carried the ball beginning with (1) Faraday's magnets, to (2) Maxwell's equations, to (3) Hertz's radio waves. Faraday, the greatest of all experimenters, discovered that the motion of a magnet inside or close to a coil of wire induces a current in the coil. Not being a mathematician, Faraday explained his experiment by assuming that the magnet is surrounded by lines of force which cause current to flow whenever they cut across a conductor. An appreciative mathematician, Clerk Maxwell, expressed Faraday's pictorial ideas in mathematical terms. In 1864 he went a step further and suggested that electrical and magnetic changes are propagated in the form of



JAMES CLERK MAXWELL



HEINRICH RUDOLPH HERTZ

waves, and theorized that these waves traveled at the speed of light, and finally that light itself is propagated in the form of waves. Although Maxwell's theory of light waves was generally accepted in England, the rest of Europe did not think much of it. In 1879 the Berlin Academy offered a prize to anyone who could throw light on this question. This prize led a young student named Heinrich Hertz to the study of Maxwell's equations. He promptly fell in love with them. Using amazingly simple means — an induction coil and a loop of wire — he was able to demonstrate just the sort of electrical waves predicted by Maxwell's theories. Even more remarkable, he was able to measure the speed of these waves and found them to have exactly the same speed as light. The electric waves created by Hertz in 1887 are now called radio waves. It would be an exaggeration to credit Hertz with the invention of radio, but he certainly demonstrated its possibility just as Maxwell predicted its existence. Hertz's work was interrupted by a severe and prolonged illness; and his untimely death at 37 was a great loss to science.



Fig. 1 — Complete schematic of first radio receiver.

Hertz's experiment attracted a lot of attention from physicists, but one untutored youth built his entire life around it. A young Italian named Guglielmo Marconi became convinced that he could transmit Hertzian waves across great distances. He was amazed that others had not jumped to the same conclusion. However, his initial attempts, using Hertz's original circuits, were limited to no more than a few yards. One of his difficulties was the total inadequacy of his receiver, which is not surprising (see Fig. 1) considering that Hertz had used a single loop of wire not quite closed at one end to detect his electric waves. The loop would respond, when the Hertz "transmitter" emitted a spark, by jumping a similar spark across the tiny gap. Sans antenna (as we know it), sans detector, sans any amplification, reception at more than laboratory dimensions was doomed.

"Long" distance radio was temporarily blocked by the lack of a sensitive detector.

Scenario for a Research Drama

The story of the origin and development of the first practical radio detector is a classic example of a long series of lone inventors contributing crumbs of knowledge to the general scientific store until someone, dipping into the collective barrel, looks at an old idea through new eyes and new needs, and transforms the old idea into a revolutionary advance. In a sense, this is what Marconi did; but the story of the first detector is even more striking, perhaps because the list of scientists involved is as long as the cast of a Hollywood spectacular.

Time: 1850 (A nice round year to begin with.)

Place: England, France, Germany, Italy, Russia, America.

Enter Pierre Guitard, a French scientist. He reads a report about dust particles in the air to other scientists. When the air is electrified, the dust particles form into small compact clusters. He cannot explain it. Fadeout. . . .

Enter S. A. Varley, an English inventor. In 1866 he is busy at work trying to protect telegraph wires as well as the poles and insulators supporting them from destruction by lightning. Guitard's observation suggests an idea to him. Varley hollows out a block of wood and fills it loosely with carbon particles and tin filings. He attaches one end of the block to the telegraph wires and the other end to ground. The idea works. How? When lightning strikes, the loose particles form a tight, compact, conducting mass which harmlessly short the flashes to ground. A minute or two later, the particles loosen enough to allow resumption of telegraph operation. Fadeout. . . .

Enter David E. Hughes, a professor of music, and inventor of the microphone; born in England, educated and naturalized in America. In 1878 (the same year he invented the microphone) he performs an experiment no one pays much attention to. His experiment proves that the discharge of a Leyden jar (an old type of capacitor) does to zinc and silver filings what lightning had done to Varley's tin and carbon filings. Fadeout. . . .

Enter Calzecchi Onesti, an Italian professor. In 1884 he publishes an article describing how copper filings cling together when subjected to a high voltage discharge in the immediate area of the filings. Fadeout. . . .



EDOUARD BRANLEY

Enter Edouard Branley, a French doctor, later Professor of Physics. Dr. Branley is interested in the way nerves carry messages to the human brain. His work leads directly to the field of electricity. In 1890, after studying the reports of his predecessors, he fills a glass tube with nickel and silver filings and plugs up each end with metal electrodes. Then he connects across his new device a battery and meter. The needle of the meter does not move — the device is apparently a poor conductor. But wait. Branley strikes a spark from a nearby battery, when lo and behold, the needle moves sharply indicating the device is now conducting. The needle continues to read a high current until the filings are jarred loose — then no current. Very slow fadeout (Branley died at the age of 93). . . .

Enter Sir Oliver Lodge, eminent British scientist, first Principal of Birmingham University, knighted by the Crown. Lodge sees in Branley's device the long awaited means of detecting Hertzian (radio) waves and gives it the name by which it becomes widely known: Coherer. Lodge does more — he overcomes one of its defects by designing a clockwork mechanism which decoheres the filings automatically. In 1894 he demonstrates the sensitivity of the coherer in a public lecture at Oxford by detecting Hertzian waves over a distance of two hundred feet. Fadeout. . . .

Enter Alexander S. Popoff, Russian physicist, who uses the Branley coherer to predict approaching lightning storms. He inserts an electrical bell in the coherer battery circuit and when lightning flashes occur that are still out of range of sight, the sensitive coherer is able to detect the atmospheric discharge and cause the bell to ring a warning of approaching storms. To improve the device, Popoff attaches the bell-ringing arm in such a way as to strike the coherer tube and instantaneously reset the filings for the next flash. In 1895 Popoff demonstrates his bell-ringing coherer by receiving an "audible" signal over a distance of 600 yards at a meeting of the Russian Physicist Society of St. Petersburg. Dissolving view. . . .



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The Stage is Set for Conclusive Experiment

Before unveiling the final tableaux, let us dispose of some rival claims. The loudest claims are for Popoff because he produced the first audible signal from radio waves — which may be true, but this hardly merits the claim that he invented radio. Similar claims have been made for Sir Oliver Lodge, although he used a galvanometer rather than a bell or telegraph ticker to register the signals. Undoubtedly Lodge exhibited successful short range radio transmission, as did Popoff a year later, but in both cases the demonstrations were of a theoretical rather than a practical nature. And while we are on this subject, something should be said for Dr. Branley since he steadfastly refused to claim anything for himself throughout his long life. His coherer, improved mechanically, but unchanged electrically, triggered the birth of modern radio.

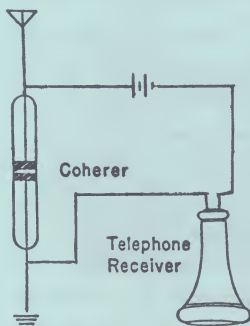


Fig. 2 — Marconi's receiver at Newfoundland in 1901.

The barrel has been filled with all manner of goodies which a clever man can put together, perhaps with a fillip of his own added, to complete a new recipe so startling as to make the world sit up and take notice. Marconi is that clever man. He took the Hertz exciter, spruced it up with more power, and the Branley coherer, evacuated the glass tube, and added his own overhead aerial and grounded rod. Very quickly he attained a distance of several miles, but this did not satisfy him. Marconi was obsessed by distance — not hundreds, but thousands of miles. (He was bitten by the DX bug, a common disease in those days which he transmitted to many others.) Gathering a staff of engineers around him, he built a more powerful transmitter, every bit of 25 kilowatts. In 1901 his signal spanned the Atlantic — a distance of 2,000 miles. The receiver he used is diagrammed in Fig. 2. Impossible, you say? But look again — there is something missing in the diagram. It does not show Marconi's aerial raised by a kite 400 feet above the earth — a typical DXer's trick.

Successors to the Coherer



GUGLIELMO MARCONI Having played its spectacular role in the opening act of the radio drama, the coherer gave way to improved and more consistent detection devices. Marconi himself introduced a so-called magnetic detector in 1902, and the American Prof. R. A. Fessenden came up with an electrolytic detector that same year. But it was not until 1904 that the first modern detector, still used today, appeared on the scene. This was the two-element thermionic vacuum tube developed by J. A. Fleming, a member of Marconi's research staff. Two years later, Lee deForest added a third element to the vacuum tube and thus created a detector that amplified the signal it detected and the Electronic Age was born.

Although the future belonged to the vacuum tube (as "futures" go in electronics), its high initial cost, high installation cost, and high operating cost, placed it out of reach of all but commercial installations. But, in this same year, Greenleaf Pickard discovered the rectifying properties of many mineral crystals, among them galena, which became the most popular detector in home crystal sets because of its low cost and high sensitivity. It had one disadvantage — the cat's whisker which was used to probe the crystal for a sensitive spot. But in return for that little trouble it was able to begin rectifying at the point of no voltage.

Some may claim that the Semiconductor Story should begin properly with the invention of the transistor in 1947. This may be true for anyone interested strictly in the technology of their manufacture, but to begin with the decisive event — the breakthrough — is to miss the most human part of the story: the fumbings, the gropings, the feeble steps that gradually picked its halting way to success. No apologies are necessary for this pattern — they characterize all areas of human endeavor.

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